Robustness of Model-Based Risk Reduction Strategies

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Introduction

- Models can predict effect of future actions; used to make decisions:
  - more reliably than human judgement,
  - more flexibly than fixed processes
  - e.g. use of COCOMO II or other software cost models is mandatory at NASA (NPR 7150.2)
- Risk reduction (including V&V) is critical and expensive part of projects
- Improvements in risk reduction can save money and/or reduce risk
- Model-based choice of risk reduction strategies:
  1. *Quantify risk* in each risk category
  2. *Quantify cost and risk reduction* for each technique
  3. Choose optimal combination of risk reduction techniques
- *Q: How much does effectiveness of chosen strategy depend on accurate quantification of risks & mitigations?*
  - ran sensitivity analysis experiments for different optimization strategies
- *A: Not much*
  - *optimized strategy nearly always beats any fixed strategy*

Optimizing Risk Reduction

- We consider here two different algorithms
- *Strategic Method* (Port, Kazman et al)
  - employed with JAXA case studies
  - algorithm gives provably optimal risk reduction strategies
    - as long as assumptions hold
  - well suited to independent V&V (IV&V)
- *Defect Detection and Prevention* (Cornford & Feather)
  - design-level identification and mitigation of system/software risks
  - developed at JPL, used for many NASA mission technologies
  - rapid elicitation of relationships between objectives, risks, mitigations
    - risks harm objectives,
    - mitigations reduce risks
  - uses a standard of heuristic search (simulated annealing) to make near-optimal selections from among dozens – hundreds of mitigations

Strategic Method

- Inputs:
  - loss potential and probability for each attribute (risk)

Attribute (i)	A1	A2	A3	A4
Loss potential for Ai	100	90	90	80
$P_{before}(Ai)$	6	5	20	15

  - cost and reduction in loss probability applying each technique to each attribute

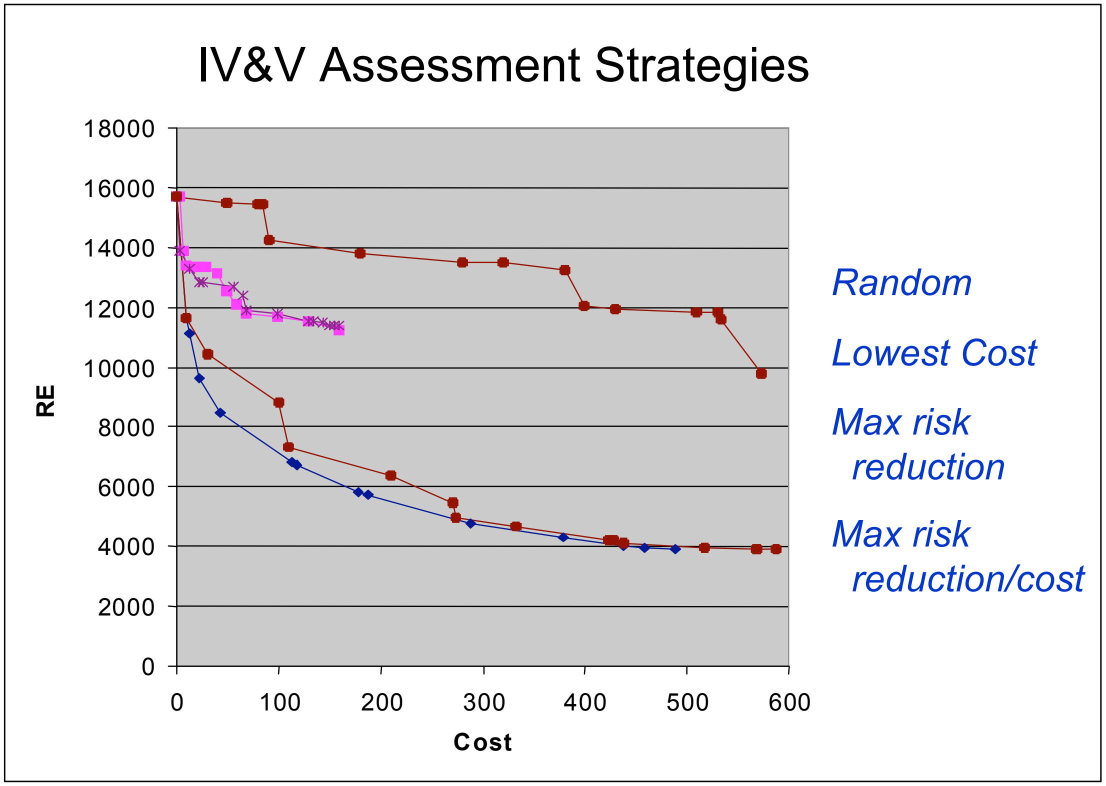
Cost / resultant loss probability Assessing Ai with Tj	A1	A2	A3	A4
T1	50 / 4	NA	10 / 15	70 / 12
T2	100 / 6	NA	NA	100 / 13
T3	NA	NA	80 / 15	80 / 12

- Output:
  - optimal order to apply techniques to attributes for any budget

Attribute	Technique	RE Change	Cost	CB	risk reduction	cumulative cost
None	None	None	None	None	15700	0
A13	T11	4050	10	405	11650	10
A7	T9	500	3	166.667	11150	13
A11	T11	1500	10	150	9650	23

Risk Reduction vs Cost

- Graph on right plots risk exposure vs cost for various strategies.
- The benefit provided by strategy is its risk reduction.
- Better strategies produce more benefit for given cost → have lower curves.



DDP

- Inputs:
  - amount (0 ≤ impact ≤1) by which each risk reduces each objective
  - amount (0 ≤ effect ≤1) by which each mitigation reduces each risk
  - cost of each mitigation
  - total budget
- Output:
  - heuristically optimized (maximal attainment of objectives) selection of mitigations for that budget

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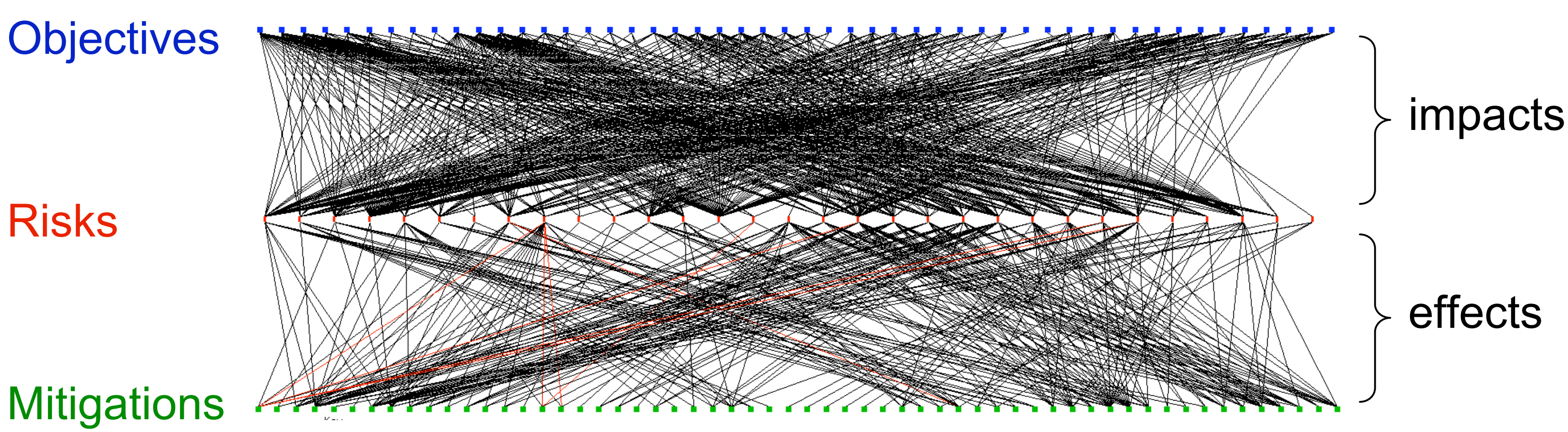
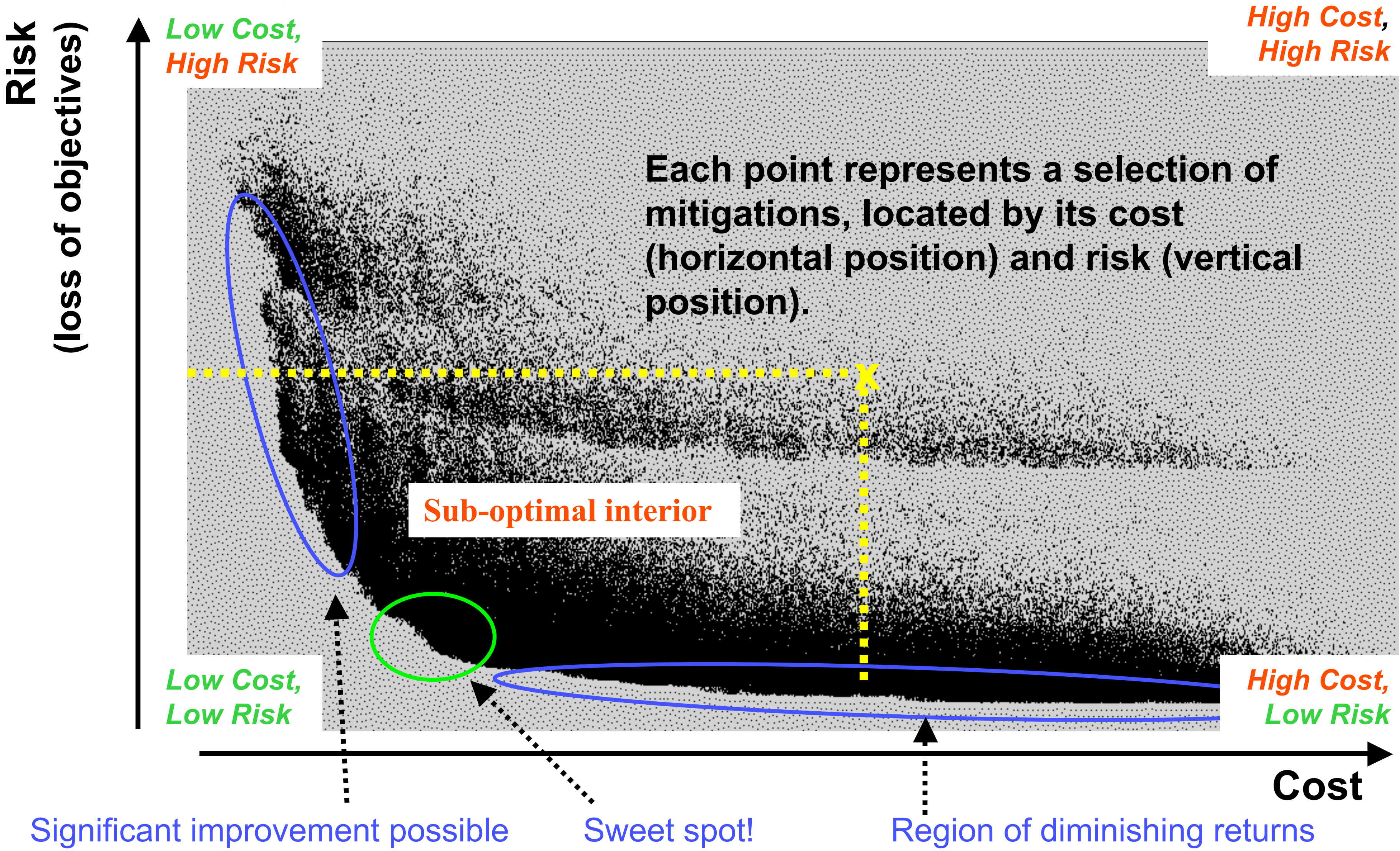
This is the topology of the connections for an actual application of DDP – note that associated with each line is the amount (impact or effect):



DDP method results

58 mitigations = 2^{58} (approx 10^{17}) ways of selecting: searches using “simulated annealing”, extended across entire cost range to reveal cost/risk tradespace



Need for Sensitivity Analysis

- Algorithms optimize strategy selection given knowledge of magnitudes and costs of risks and mitigations.
- Hard to know these things in advance –
  does (in)accuracy effect validity of decisions reached by applying these algorithms?

- Questions:
  1. *How much does effectiveness of chosen strategy depend on accurate quantification of risks & mitigations?*
     – experiments to vary actual from specified effectiveness or risk
  2. *How much does optimized strategy improve on fixed* strategy?*
     – experiments evaluate difference between optimized strategy, and each of four kinds of fixed strategy (a) random, (b) “reasonable”, (c) cheapest, (d) “great” (optimal for nominal risk levels)

  * Fixed strategy = for a given budget, a predetermined selection of mitigations that is the same no matter the problem

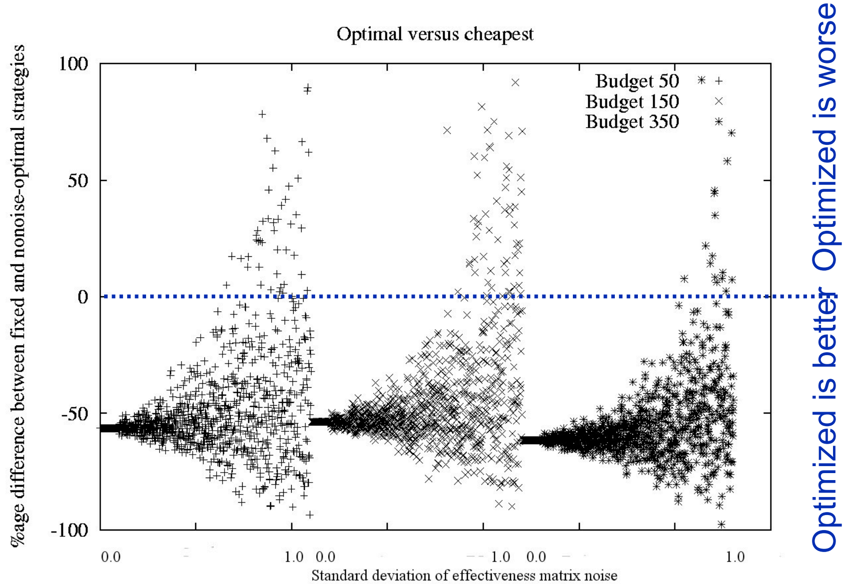
Sensitivity wrt Effectiveness Matrix

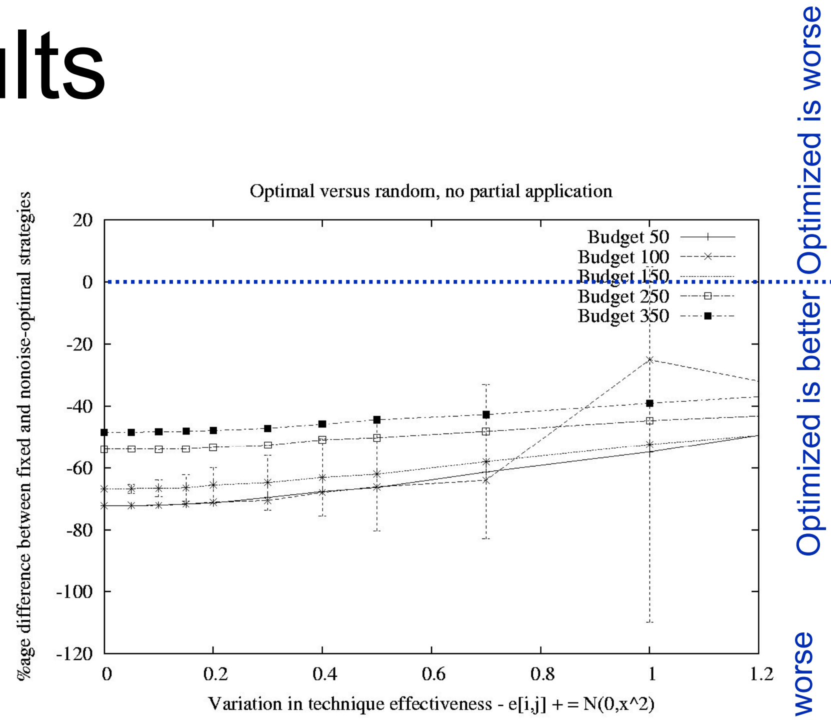
- *Knowledge of risk or technique effectiveness is often uncertain.*
- Compute effectiveness matrix: effectiveness of technique T_i on attribute A_j, $\rho^0_{ij} = (P_{before}(A_j)-P_{after}(A_j, T_i))/P_{before}(A_j)$

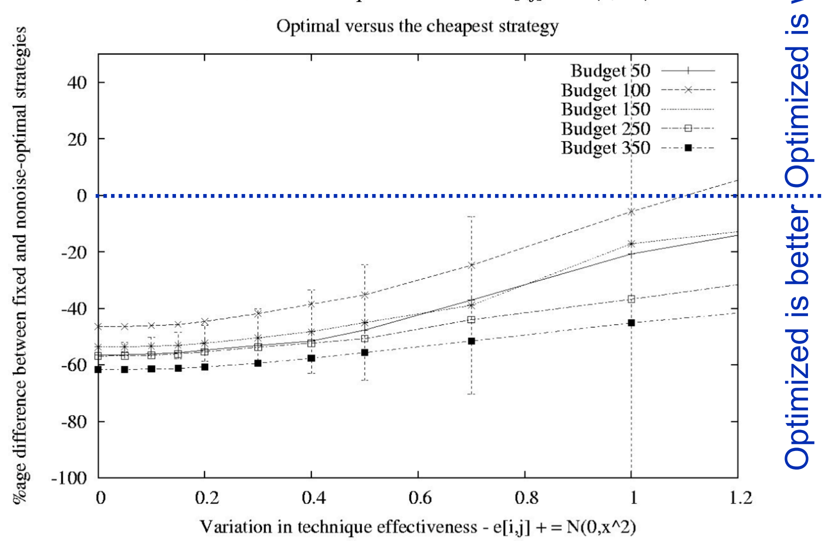
1. Repeatedly*:*
   a) Pick fixed budget $b \in \{50,100,150,200,250,300,350,400\}$
   b) Pick noise level $\sigma \in \{0, 0.05, 0.1, 0.15, 0.2, 0.3, 0.4, 0.5, 0.7, 1.0\}$
   c) N (=1000) times:
      i. Add noise to effectiveness matrix: $\forall$i,j, $\rho_{ij}=\|\rho^0_{ij}+N(0, \sigma^2)\|$
      ii. Evaluate %age difference between S_{opt} and S_{fixed}, $\Delta=(\delta RE(b, S_{fixed})- \delta RE(b, S_{opt}))/\delta RE(b, S_{opt})$
   d) Add a point to the plot with *x* coordinate σ, *y* coordinate the mean value of Δ, and if desired add error bars to that point to indicate the standard deviation in Δ

Results

- Optimized strategy:
  - significantly better than random strategy
  - significantly better than cheapest strategy
  - even for inaccurate knowledge of effectiveness or risk







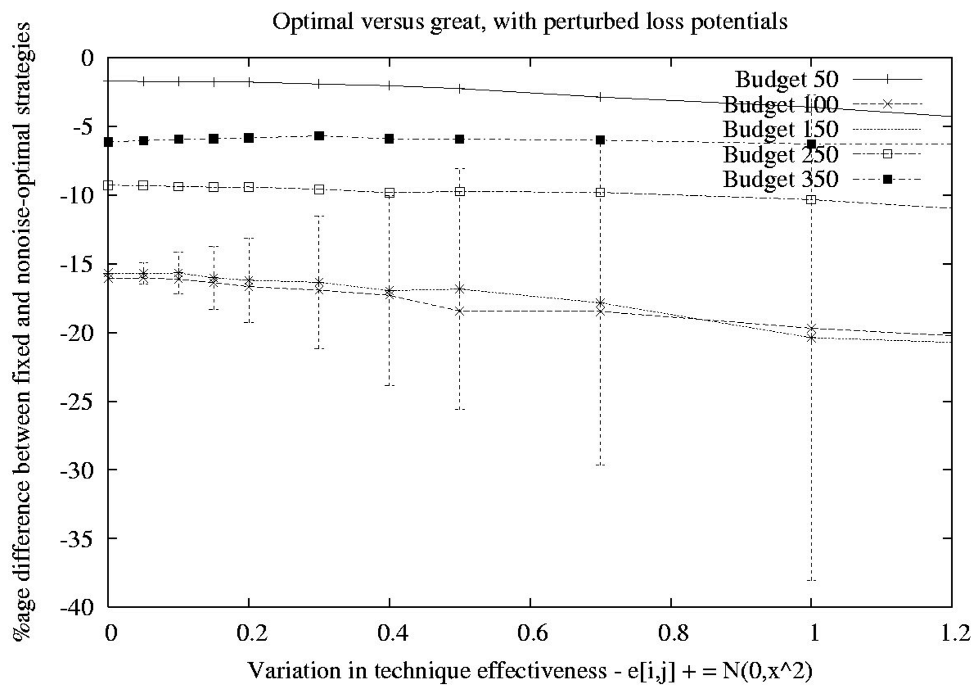
Comparison with Optimal Fixed Strategy

- *Strategic Method adapts strategy to risk profile*
  - *maybe we could just optimize once, for typical risk profile?*

1. Use Strategic Method to calculate optimal strategy S_{fixed} given loss potentials, L_j for each attribute A_j
2. For each L_j randomly choose L'_j from $\{0, L_j, L_j \times 1.5\}$
3. Use Strategic Method to calculate optimal strategy S_{opt} for perturbed loss potentials
4. Perform sensitivity analysis wrt effectiveness matrix as before

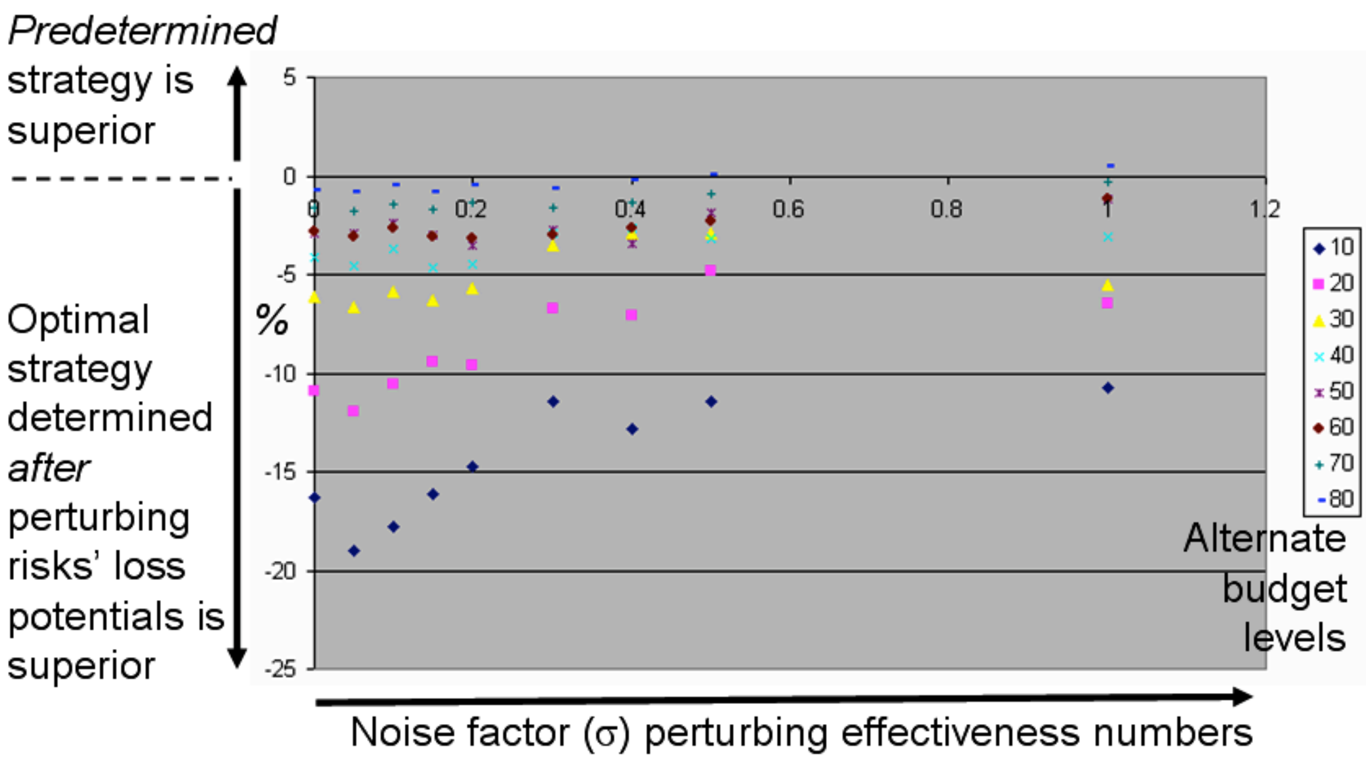
Results

- Graph shows result from a typical choice of perturbed loss potentials.
- Optimal significantly better than ‘great’
- *Fixing a strategy to that which is optimal for a <u>typical</u> risk profile is usually **inferior to an optimization based on the estimated risk profile,** even in the face of inaccuracies in those estimates.*



Sensitivity analysis of DDP

- DDP uses different optimization algorithm (simulated annealing) and different calculation of risk reduction.
- Strategic method experiments repeated with DDP* - conclusions for Strategic Method hold for DDP too:



*DDP changed to allow fractional application of the final V&V strategy, as per Strategic Method

Conclusions

- Sensitivity analysis of strategic method and DDP wrt knowledge of technique effectiveness and risk reduction
- *Optimized strategy <u>is</u> better than alternatives even when significant uncertainty exists in estimates of effectiveness and risks.*

- *Significant cost reductions or risk reductions are achievable:*
  1. *Estimate magnitude of risks + effectiveness & costs of available mitigations.*
  2. *Choose optimal strategy (e.g. using Strategic Method).*